Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 3 (2012) 555 – 560

www.elsevier.com/locate/procedia

45th CIRP Conference on Manufacturing Systems 2012

Virtual Ergonomics and Time Optimization of a Railway Coach Assembly Line

A. Marzano[a,*], K. Agyapong-Kodua[a], S. Ratchev[a]

[a]*Precision Manufacturing Centre*, *Dept of Mechanical, Materials and Manufacturing Engineering*, *University Park Nottingham*, *NG72RD*, *UK*
* Corresponding author. Tel.:+44(0)1158468834; fax: +44(0)1159513800 .*E-mail address*: adelaide.marzano@nottingham.ac.uk

Abstract

The recent drive towards timely multiple product realizations has caused most Manufacturing Enterprises (MEs) to develop more flexible assembly lines supported by better manufacturing design and planning. The aim of this work is to develop a methodology which will support feasibility analyses of assembly tasks, in order to simulate either a manufacturing process or a single work-cell in which digital human models act. The methodology has been applied in a case study relating to a railway industry. Simulations were applied to help standardize the methodology and suggest new solutions for realizing ergonomic and efficient assembly processes in the railway industry.

Keywords: Work-cell assembly simulation; Ergonomics analyses; Digital human modelling

1. Introduction and problem statement

Nowadays several tools and methods allow designers to reach significant target in the transportation design. In many cases the efforts are focused on new designing solutions to get the best fitting with customer requirements [1-2]. Also several tools implemented in current software for the integrated design are dedicated to assure designers creativity. A different approach is necessary for the design of an existing vehicle to assure a better flexibility during the operating phases and to introduce ergonomic requirements. Recently, the development of product design impulses the research on relations between human, machine and environment. It brings ergonomics to a practicable stage, especially in railway product design [3] and workplace task ergonomics analysis [4]. With the development of supercomputing, computer graphics, virtual reality and high performance graphics system, the research on ergonomics is extended to virtual environment platform that is based on 3D-graphics, interactive, physics based model, and provides real-time simulation and evaluation [5]. In virtual assembly [4], process design [6], verification of maintenance processes [7-8] and others, it has been applied and incorporated in the framework of virtual prototype development. As a key step of product life cycle, it is very important for ergonomics simulation to shortcut test/development cycles, lower development costs, improved quality and enhance safety [4, 9].

The paper presents the tools, the methods and the procedural flow adopted in the designing of a manufacturing process for ergonomics and time optimization in a virtual environment. Particularly as case study a railway coach manufacturing process was considered in order to test the procedural flow showed in Figure 1.

The design of the manufacturing process was divided into three main phases in accordance with the approach adopted:

- Phase I: Simulation of the assembly line sequencing;
- Phase II: Workplace assembly sequencing;
- Phase III: Ergonomics analysis.

After a brief description of the parts that make up a train and the current railway vehicles production, in the following sections we focus on the deployment of the

doi:10.1016/j.procir.2012.07.095

phases aforementioned. Particularly, for phase I we considered the company's layout analysis, assembly lines and logical flow of components, in order to provide a reduction of the standard times and production costs to realize the end-product. Everything was simulated through the use of Delmia Quest software by Dassault Systemes, which has provided the tools and techniques needed to deal with this type of analysis. As index to evaluate the different solutions proposed we used the Flow value analysis.

Subsequently, in phase II and III, workplaces assembly sequencing and ergonomics analysis are analyzed in detail, in order to determine the best assembly sequence of each workplace for time saving and ergonomic requirement fulfillments. The assembly simulation has been developed by using the human modeling software Jack 5.0 of Siemens PLM software [10], to assess the interaction between the operators involved in the assembly line, the necessary equipment, and the components of the group. The virtual manikin allowed us to define where and how many operations can be performed in the workplace assembly sequence.

Human Modeling software allow designers to indicate all the possible postures and all joints motions that the digital human has to assume in order to execute a specific assembly task. A task cannot be identified with a single posture or a single joint motion but it has to be considered as a consistent and harmonic sequence of postures assumed by the operator. Within a sequence it is possible to indicate the critical posture, which is potentially the most dangerous in relation to the risk of muscular-skeletal diseases. A task, generally, is not characterized by a unique and defined postural sequence but, on the contrary, it is possible to recognize several sequences that, mainly, depend on the access path and on the geometrical constraints of the working environment. The discomfort level of each sequence is closely linked to the relative critical posture. So, the problem consists of determining the critical posture related to each execution method of an assembly task and selecting the most comfortable.

First objective of an assembly sequence design is to obtain the right trade-off between time and performance; from this point of view the feasibility requirement of the manual assembly task (in a short time) is more important than the ergonomics of the same activity. The contemporary optimization of both characteristics (time execution and ergonomics of assembly tasks), is hard because it needs a design solution that have to match with other characteristics of a vehicle such as style, component dimensions, geometric constraints and quality performances. Nevertheless, even though the "best solution" related to the ergonomic design of an assembly activity is difficult to achieve by means of quantitative methods, the methodology proposed gives the possibility to obtain the "optimal solution" selecting the modus operandi of the worker. The execution of each elementary task is performed in a comfortable way taking into account the time associated to its realization. The choice of this optimal solution is determined, as described in section 5, combining a Posture Evaluation Index (PEI) and Method-time measurement (MTM), [10].

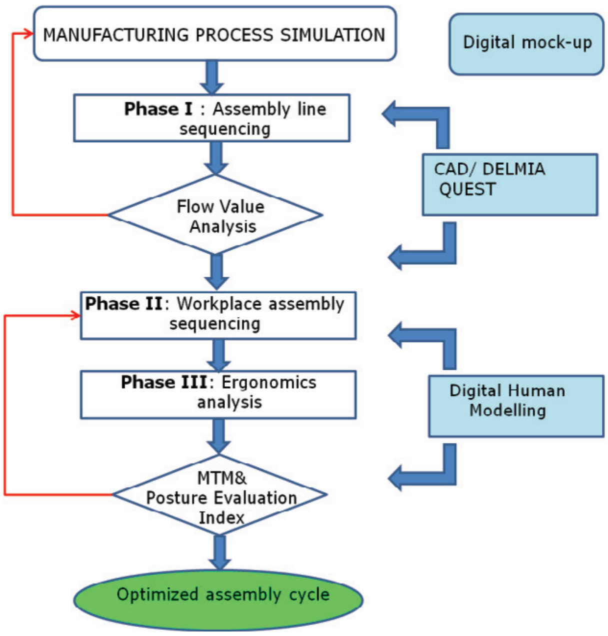

Fig. 1. Procedural flow adopted in the designing of a manufacturing process

2. Railway vehicle production

With a view to bringing innovations in the production cycle of a railway coach, it is necessary to examine with attention the different moments that lead to the design of a train, taking into account the techniques and technologies in use. A railway vehicle is essentially composed by two principal systems: the case and the bogies [11]. The case consists of a metallic structure of steel or aluminum alloy (in which four main modules are indicated: headstocks, body, body sides and imperial), the electrical equipment (illumination, signaling, power), the pneumatic system (brake, and other services), the furnishing (seats, baggage racks, doors, divining walls, lining), the auxiliary equipment (conditioning, hygienic services, fire- fighting) and, finally, the connection parts of the vehicles (hook-ups, repelling, electric and pneumatic couplers). The bogie is, instead, composed by a metallic structure of steel (body), by the wheel arrangement, by the reduction gear (only for motive bogies), by the electrical equipment (signaling and control), by the pneumatic system (brake), by the parts of the suspensions (springs, dampers), by the auxiliary equipment (pneumatic sander) and, finally, by the interface parts with the case. The production flow of a railway vehicle is realized through four phases: component preparation; assembly structures; sandblasting and painting; final assembly [11-12]. In this manufacturing process, about 80% of the time is needed for the assembly of the case. For this reason the railway industry is investigating the use of new technologies and methods in order to improve the assembly process. In [11] is presented an innovative assembly cycle of railway vehicles that improve the manufacturing process thanks to the virtual reality (VR) technologies. The paper seeks to contribute to solving this problem and proposes an optimized assembly cycle using simulation techniques in virtual environments.

3. Phase I: design and simulation of the railway coach assembly line

Simulation of the manufacturing system processes has allowed the development of productivity and cost analysis for existing equipment, research bottlenecks, simulations of stationary plant for machine failures and the verification of production plans and Just-In-Time (JIT) scenarios. Through this simulation, we evaluated the interaction between the operators involved in the assembly line, the necessary equipment, and the flow materials of train components. On the basis of the model built we carried out simulation tests to determine the performance of the layout and to make improvements either in the arrangement of work stations along the line production, or in the management of production, i.e. percentage of utilization of machines, MLT (Manufacturing Lead Time) that is the time it takes to follow the product production line and WIP (work in progress) to reduce storages of semi-finished products.
Each workplace is represented by a black box, modelled with Solid-Edge software respecting the distances among equipment, and imported in Quest environment as "machine", elements necessary for the processing of the parties and that allow the realization of the assembly cycle. In order to characterize the "machine" we also need to define the cycle time, i.e. the time needed the equipment to perform the operation, and assign to them logic to allow the routing of the parties. The next step was to create parts, each of a different colour, representing the single components that are processed, which are shown in Figure 2.
The last steps were the creation of the buffer required for the accumulation of the parties, and the creation of sources and sinks, elements which provide generation/destruction of parts: the first used for the creation and entry of the parties into the line production, the second to release them from the model. Having built the machines, buffers, sources and sinks they have been placed on the grid reference, in order to respect the distances and layout.
Moreover, they were joined by special transport elements represented in our model by conveyor belts, as shown in Figure 2(e). They were created with the "layout" method that allows the creation of the element according to the specifications required by the user, through the definition of the path along which we will extrude the section of the tape. These elements make the logical flow of parts evident and visible, how the single components go through the workplaces to complete the railway assembly cycle.

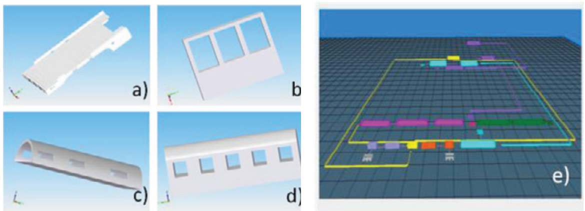

Fig. 2. Modular train components: a) body module; b) body sides (6 components); c) imperial; d) case; e) Digital model of the layout configuration

3.1. Optimization model: flow value analysis

Delmia Quest software [13] provides tools that allow designers to achieve the results of the simulations run on the model and obtain quantitative information about the behavior model. On one hand, these tools allow us to obtain statistical reports and charts (both standard and customized by the user) at the end of the simulation, on the other hand provides the ability to display model data in a dynamic way, updated at defined time intervals with the development of the simulation.

Using this tool we can obtain information such as average usage and cycle time machine, number of parts processed at the end of the simulation, percentage of use of individual buffer. These statistics allow us to identify the requirements that a correct layout design have to answer, such as:

- To minimize the cost of transport of the materials;
- To minimize the components stored;
- To use the available space in the most effective way;
- To avoid unnecessary capital investments;
- To effectively use of the workforce (labor).

After running each simulation, a report on all the data pertaining to the run can be obtained using Quest's single run output. Reports, moreover, are broken down by element class (machines, buffer, labor, part, etc.), then by individual element (machines_1, buffer_1, labor_1, etc.).
Once the bottleneck was identified, we tested a few additional models to check how a new layout and additional machines would impact the bottleneck.

Workplaces from 1 to 10 were tested using this simulation model. When determining the optimal layout, two measures were taken under consideration. The first one is the average wait time per part (module) per buffer. This is done by finding the average wait time at each buffer and divided by the number of components.
Figure 3 shows the outcome. We can see that according to this figure, workplace 8 is the optimal and workplace 1 is the worst. Another measure is the average time that each part took at the machines. This measure suggests that the optimal workplace is n.10.
Although the two methods yield two different results, it was determined that the time at workplace 1 have to be saved. In this study, three different solutions are proposed, with the aim to reduce the lead time and time of storage of components, making different assumptions about the delivery time of extruded on building slip.
The alternatives are the following: the first is characterized by a rate of components on building slip shorter than the time cycle of operations; the second, the components are already available on building slip; the third is characterized by a rate longer than the time cycle.

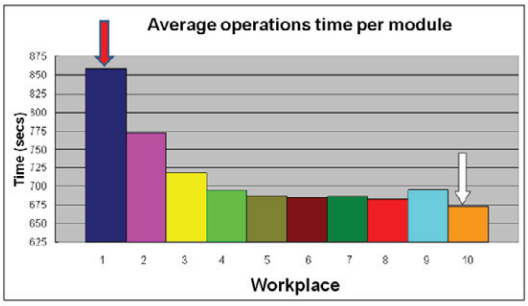

Fig. 3. Average waiting time of each workplace at the buffer

Analyzing the results obtained from the three simulations, we can see how the waiting times of components change in terms of time buffer occupancy; indicate the bottlenecks of production system and finally which workstations need to be modified in order to optimize the layout. The choice of the optimal solution, between the three proposals, was carried out using the FVA (Flow Value Analysis). The FVA method allows us to estimate the efficiency of the flow materials within the production system. From Table 1, it is evident, therefore, that the third proposal is the best one. Having determined the optimal solution, the focus has been shifted on the single workplaces, number 1 and 2, dedicated to the front body module, as the average operations time per module resulted the longest (see Figure 3). Through the use of the human modeling software Jack 5.0 [13-14], we identified and simulated in detail the assembly operations sequence in a virtual environment.

Table 1. Flow value analysis result

Flow Value Analysis Result			
	Rate< Tcycle	Rate=Tcycle	Rate> Tcycle
IFVA	0.84	0.88	0.94

4. Phase II: Development and simulation of the workplace assembly sequence

The shed used to the assembly cycle is constituted by 5 identical spans predisposed for the complete coach assembly. In each span there are 10 workplaces.
The study of the assembly sequence is developed in phase of concept, when it is possible to compare alternative solutions without creating limitations to the following phases. In the case study, since the shed is still being restructured, there is the possibility of operating any workplace layout configuration whatsoever. The same shed is divided in spans of 21m x 170m. Each of them is divided in 10 workplaces of equal area (7m x 27 m). In order to transport the components toward the workplaces or to transfer the completed modules (body, body sides, imperial, cabin and headstock) to the final assembly, two independent bridge crane was adopted, with capability of lifting of 20 tons each.

4.1. Workplace 1

The structure used for this operation is represented in Figure 5. Having positioned the head structure on building slip, the worker complete it with locking screws, paying particular attention to centre it perfectly on the equipment through the central and front support that are blocked in vertical position by means of plugs .
The following operation is the positioning of the right and left spars on the building slip, blocking them centring axis with the reference built on tool. Once blocked the three pre-assemblies on the equipment, the worker positions the two spars with the head structure and place stakes boost among them in order to respect the width of the module (Figure 4). To complete the assembly, the floors, previously brushed, are taken and blocked on the building-slip assembly aligning them with the components already positioned. Having locking and welded all the pre-assemblies on the building-slip the worker performs the welding operations with a specially shaped welding machine.
Having completed this phase, the worker brush all the components welded and re-lease the blockages.
The operations described have been analysed through the MTM (Methods Time Measurement) [10, 15] using the Predetermined Time Analysis, a tool implemented in the Task Analysis Toolkit of the software Jack.

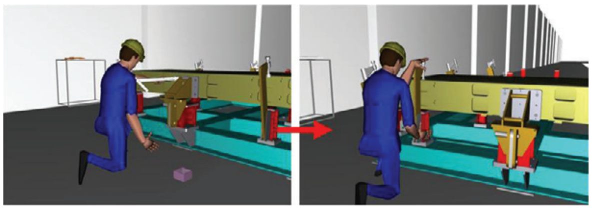

Fig. 4. Locking sequence of the head structure

The principal limit of the MTM techniques is the lack of an ergonomic analysis: they do not take into account the study of human posture and efforts in the task analysis. Therefore, the application of opportune ergonomic corrective actions bring towards more realistic time estimations. Previous studies [10,16] have proved that opportunely modified MTM systems do contain ergonomics information [17-19] and can be the base for ergonomic evaluations. As aforementioned, this module has to be worked on both sides, we have used another building slip, named the rotating equipment, which allows the worker to do the same welding and brushing operations on the other side of the module.

4.2. Workplace 2

The structure used, as rotating equipment, is represented in Figure 5. The front body module, almost complete, is transferred to the workplace 2 through the use of a bridge crane and positioned on the rotating equipment.

Here the front body module is rotated of 180° to be worked on the opposite side. The first operations are positioning and blockage of the pre-assembly with screws and then brushing of the parts to be welded (Figure 5).

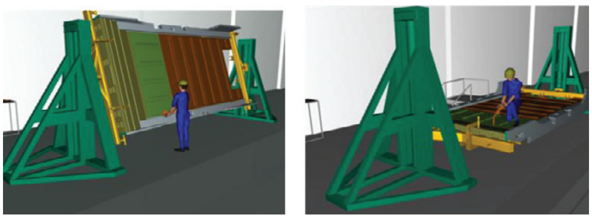

Fig. 5. Brushing and welding operation on rotating building slip

5. Phase III: Ergonomic Analysis Using the Posture Evaluation Index (PEI)

As aforementioned in the previous section the work-cell time evaluated through MTM is an approximated time that needs to be incremented introducing ergonomic considerations. The ergonomic analyses of the worker postures have been carried out in a virtual environment by using the Jack software. Simulating the manual tasks in virtual environment [20-21], the worker postures have been evaluated using the Posture Evaluation Index (PEI), developed and illustrated in [22-25].

The PEI integrates the results of the Low Back Compression Analysis (LBA) [26], the Ovako Working Posture Analysis (OWAS) [27], and the Rapid Upper Limb Assessment Analysis (RULA) [28], in a synthetic a-dimensional index able to evaluate the "quality" of a posture:

$$PEI = \frac{LBA}{3400N} + \frac{OWAS}{3} + \frac{RULA}{5} \qquad (1)$$

PEI can range between the minimum value 0.47 (i.e. no loads applied to the hands, values of joints angles within the acceptability range) and the critical value 3.00 (when all the ergonomic indexes reach the critical value). For each operation we have indicated the most critical posture characterized by the higher PEI value. The two operations shown in Figure 7 respectively overcome and approach the critical value because both OWAS and RULA are higher than their critical value due to uncomfortable postures assumed by the worker. However for these tasks, characterized by non repetitive activities, critical postures can be accepted. We only have to consider when a critical posture requires a longer execution time [29]. The idea is to consider the discomfort of a posture as a factor that influence the time needed to perform a task. In [29] corrective factors have been defined that correlate time calculated by MTM to the most critical posture assumed by the worker during the task. The proposed approach allows designers to estimate with an "acceptable" error the time needed to perform maintenance tasks or assembly line operations characterized by a low level of automation and where human factors play a crucial role in the first phases of product design development.

In this case, according to the approach summarized in Table 2, we have to apply an increment of 52% to the time corresponding to external blockage of the left spar operation and an increment of 11% to the internal blockage of the left spar operation.

The main experimental result is that ergonomics of postures has a great influence on human performance during the tasks and therefore on times: the more the postures are uncomfortable, the more the operation time increases.

Table 2. Corrective coefficients function of reference PEIs [29]

PEI	Corrective Coefficients	
1	1	c_1
2	1.11	c_2
3	1.52	c_3

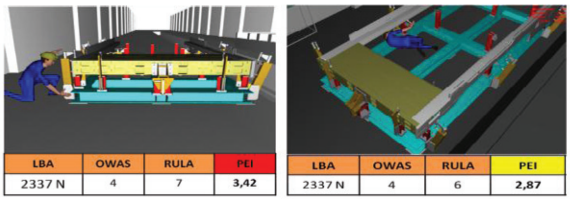

Fig. 6. External blockage of the left spar and internal blockage of the left spar

6. Conclusion and future works

To date, railway development process methodologies have remained traditional, if compared with those of major automotive companies. In recent years, the main objective of railway companies has been (and continues to be) to reconcile high quality and a high level of innovation with low costs of development and production. This work represents a first step in this direction. Through virtual reality software and CAD/CAM tools it is possible to merge the development and the engineering processes of a railway vehicle. This work describes an approach for the development of new methodologies for planning the production line according to ergonomics requirements fulfillment and time saving. In this way, by simulating both mechanical and human performance in a virtual environment, it is possible to anticipate, and consequently avoid, critical errors in the assembly process design. In future, the same methodology can be applied to other subgroups of a vehicle. The positive result is that it offers the designer freedom to test different new solutions, since the tool that they have available allow them the contextual experimentation.

References

[1] McDonagh, D., Bruserberg, A., Haslam, C,: Visual product evaluation: exploring users emotional relationships with products. Appl. Ergon. 33, 241-240 (2002).

[2] Matzler, K., Hinterhuber, H.H.: How to make product development projects more successful by integrating kanos model of customer satisfaction into quality function deployment. Technovation 18(1), 25-38 (1998).

[3] Bennet, G. R., 1996, The application of virtual prototyping in development of complex aerospace products. Virtual Prototyping Journal, I(1), 13-20.

[4] Rajan, Venkat N., Kadiresan, S., Jeffrey, E. F., 1999, Accessibility and ergonomic analysis of assembly product and jig designs. International Journal of Industrial Ergonomics, 23, 473-478.

[5] Arzi, Yohanan, 1997, Methods engineering: Using rapid prototype and virtual reality techniques. Human Factors and Ergonomics in Manufacturing, 7(2), 79-95.

[6] de Sa, Gomes, A., Zachmann, G., 1999, Virtual reality as a tool for verification of assembly and maintenance processes, Computer & Graphics, 23, 389-403.

[7] Stuering, S., Schumann, M., 1999, Next generation maintenance training system, VR news, 8(10), 16-19.

[8] Di Gironimo G., Marzano A., Papa S., 2006, Design of a Virtual Reality Environment for Maintainability Tests and Manufacturing Systems Simulations. In Proceeding of International Conference CIRP-ICME 2006, 25-28 luglio, Ischia Italia.

[9] Weyrich, M., Drews, P., 1999, An interactive environment for virtual manufacturing: the virtual workbench, Computer in Industry, 38, 5-15.

[10] DI Gironimo G., Di Martino C., Lanzotti A., Marzano A., Russo G.. Improving MTM-UAS to predetermine automotive maintenance times. International Journal on Interactive Design and Manufacturing, online first DOI: 10.1007/s12008-012-0158-8, 2012.

[11] Various Authors: Research and developed department Firema Trasporti. Descrizione dell'attività produttiva. Internal documentation, pp 1–6 (2003).

[12] Di Gironimo G., Marzano A, 2006. Design of an Innovative Assembly Process of a Modular Train in Virtual Environment. International Journal on Interactive Design and Manufacturing, Vol. 1 No. 2 June 2007 pp.85-97.

[13] Delmia/Quest User Manual, Chapter 1.6. Delmia/Quest 2006.

[14] Various Authors: Handbook Jack 4(1), (2005).

[15] Maynard, H.B., Stegmerten G.J., Schwab j.l.1948, Methods-Time Measurement, NY, McGraw-Hill.

[16] Dempsey P.G., Mathiassen S.E., 2006, On the evolution of task-based analysis of manual materials handling, and its applicability in contemporary ergonomics, Applied Ergonomics, 37, 33-43.

[17] Laring, J., Forsman, M., Kadefors, R., Ortengren, R., 2002, MTM-based ergomonic workload analysis, International Journal of Industrial Ergonomics, 30, 135-148.

[18] Udosen, U.J., 2006, Ergonomic workplace construction, evaluation and improvement by CADWORK, Int. J. Ind. Ergon., 36, 219-228.

[19] Cimmino, A., Longo, F., Mirabelli, G., 2009. A multi-measure-based methodology for the ergonomic effective design of manufacturing system workstations, International Journal of Industrial Ergonomics, 39, 447-455.

[20] Abshire, K.J., Barron, M.K.: Virtual maintenance: Real world application within virtual environments. In: Proceedings of Reliability and Maintainability Symposium, Ohio (1998).

[21] Various Authors: On line Guide Jack 4(1), (2005).

[22] Caputo F., Di Gironimo G., Marzano A., 2006. Ergonomic optimization of a manufacturing system work cell in a virtual environment, Acta Polytechnica Journal, vol.46 No. 5/2006. pp.21-27.

[23] Di Gironimo G., Monacelli G., Martorelli M., Vaudo G., 2001. Use of Virtual Mock-Up for Ergonomic Design. Proc. of 7th International Conference on The role of experimentation in the automotive product development process ATA 2001. Florence, Italy.

[24] Caputo F., Di Gironimo G., Monacelli G., Sessa F., 2001. The Design of a Virtual Environment for Ergonomics Studies. Proceedings of XII ADM International Conference, Rimini, Italy.

[25] Di Gironimo G., Monacelli G., Patalano S., 2004. A Design Methodology for Maintainability of Automotive Components in Virtual Environment. In Proceeding of International Design Conference – Design 2004, Dubrovnik.

[26] Chaffin, D.B., Anderson G.B.J., Martin B. J., 1999. Occupational Biomechanics. Wiley John & Sons Incorporated, ISBN 0-471-24697-2, 1999.

[27] Karhu U., Kansi P., Kuorinka I. Correcting working postures in industry: a practical method for analysis, Applied Ergonomics, 8, pp. 199-201, ISSN: 0003-6870, 1977.

[28] Health and Safety Executive, Work-Related Upper Limb Disorders- A Guide to Prevention. HMSO, London, UK, ISBN 0717604756, 1990.

[29] DI Gironimo G., Di Martino C., Lanzotti A., Marzano A., Russo G.. A Virtual Ergonomics approach to predetermine after-sales services times in automotive industry. In Proceeding of IDMM, Virtual Concept 2010, Bordeaux, France.